Barium Enhanced Blue Stragglers in Open Cluster NGC 6819

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K. Milliman, R. Mathieu, & S. Schuler 2015
Motivation

Non-standard stars are ubiquitous.

Blue stragglers, yellow giants, sub-subgiants are not anomalous or rare.
Motivation

Blue Straggler Formation

- Stellar *collision* during dynamical encounter.
- **Merger** in hierarchical triple.
- **Mass transfer** from an evolved companion.

  Nucleosynthesis within the giant ends up on the surface of the blue straggler.

  Red Giant (Case B) \(\rightarrow\) C, N, O

  AGB (Case C) \(\rightarrow\) *s*-process, **barium**
47 Tuc; Ferraro et al. 2006

Carbon and oxygen anomalies
\[ \rightarrow \text{CNO burning} \]
\[ \rightarrow \text{mass transfer from RGB star.} \]
NGC 188 Results

- $P \sim 1,000$ days
- $M_2$ peak $0.5 \, M_{\odot}$
- White dwarf detections
- **HST, COS spectra**

Case C mass transfer with AGB donors $\rightarrow$ look for barium.
NGC 6819

- Open cluster
- 2.5 Gyr, [Fe/H] = +0.09
- Observations in July 2014
- Hydra at WIYN 3.5 m
  R ~19,000
- Ba II at 5853.7 Å
Results: Enhanced BSS!

One Double-lined binary
(flux from secondary)

- Period = 300 days
- Eccentricity = 0.23
- \( \frac{L_2}{L_1} = 0.35 \)
- \( q = 0.79 \)

[Wavelength vs. Relative Flux plot]

- [Ba/Fe] = +1.32 for the primary component
- [Ba/Fe] = +0.02 for the secondary component

L_2/L_1 = 0.35

q = 0.79
Results: Enhanced BSS!

Four “Single” Stars

Red = solar barium

Blue = fits with enhanced barium
Results

Error bars represent range in values from adjusting parameters.

Temperature: ± 200K

log (g): ± 0.2 dex

\( v_t \): +0.5 km/s (at least)

NLTE estimated at 0.05 dex

(Korotin et al. 2011)
Narrow CMD Location

Between evolutionary tracks for 1.75 $M_{\text{Sun}}$ and 1.95 $M_{\text{Sun}}$
No RV Companions?

- RV observations over 24 years!
- Very solid, unvarying RVs.
- Monte Carlo simulation we detect:
  50% of binaries at 15,500 days
  (780 AU, 42 years)
  25% of binaries at 40,000 days
  (1,500 AU, 109 years)
  → LONG period or single
Dynamical Encounters?

- Case C expect 1000-day, BS-WD
- Hard-soft limit $10^5 - 10^6$ days.
- Hard becomes harder.
  More likely to shrink binary.
- Energy equipartition.
  **Kick out white dwarf** and leave blue straggler in a binary.
Dynamical Encounters \( \approx 1 \)

- Case C = 1000-day, BS-WD
- Hard-soft limit \( 10^5 \) – \( 10^6 \) days.
- Hard becomes harder. More likely to shrink binary.
- Energy equipartition. Kick out white dwarf and leave blue straggler in a binary.

One Double-lined binary (flux from secondary)

- Period = 300 days
- eccentricity = 0.23
- \( L_2/L_1 = 0.35 \)
- \( q = 0.79 \)
Universal Formation Channel?

Four Open Cluster BSS:
NGC 7789, NGC 6819, M67, NGC 188

Fig. 6. The $P - e$ diagram for CEMP-s and CH stars (crosses; squared crosses correspond to carbon dwarfs), and barium stars (from Gorlova et al. 2013, filled squares: strong barium stars – Ba4 and Ba5; open squares: mild barium stars – Ba1 to Ba3, according to the classification by Lü et al. 1983).
Universal Formation Channel?

Fig. 6. The $P - e$ diagram for CEMP-s and CH stars (crosses; squared crosses correspond to carbon dwarfs), and barium stars (from Gorlova et al. 2013, filled squares: strong barium stars – Ba4 and Ba5; open squares: mild barium stars – Ba1 to Ba3, according to the classification by Lü et al. 1983).

Jorissen et al. 2015

Four Open Cluster BSS:
NGC 7789, NGC 6819, M67, NGC 188

14%
80%
These BSS are Old

+1.0 dex barium → $2 M_{\text{sun}}$ star → age = 1 Gyr
(naïve, simplified picture)


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<th>Mass</th>
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<th>Final [Ba/Fe]</th>
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<td>1.3</td>
<td>0</td>
<td>...</td>
</tr>
<tr>
<td>1.5</td>
<td>5</td>
<td>+0.65</td>
</tr>
<tr>
<td>2.0</td>
<td>10</td>
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Age Limit for Barium Marker

**N-body Models**

![Graph showing frequency vs BS Age Since MT (Myr)](image)

- **Geller et al. 2013**

**AGB Models**

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*Cristallo et al. 2009*

**Lifetime** $1.5 \ M_{\odot} \approx 3$ Gyr

**Longest lived BSS** $\approx 2$ Gyr

**Age limit** $\approx 5$ Gyr

*(Solar metallicity)*
NGC 188 (7 Gyr) Results
Summary

- 5 barium enriched BSS in OC NGC 6819 (2.5 Gyr).
- Three are ~1 Gyr old.
- Occupy a narrow region of CMD.
- None have evidence of WD companions.

Periods over 15,500 days.

Formation?